

MONTHLY WEATHER REVIEW

JAMES E. CASKEY, JR., Editor

Volume 89, Number 10

Washington, D.C.

October 1961

CLOUD STREETS OVER THE CARIBBEAN SEA¹

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[Manuscript received June 23, 1961]

ABSTRACT

Bands of cumuliform clouds over the Caribbean Sea as observed by TIROS I are described. The possible relationship between the occurrence of these bands and the vertical structure of the horizontal winds is discussed. The cloud street orientation is compared with the wind direction.

1. INTRODUCTION

The meteorological satellite, TIROS I, [1] presented an opportunity to view the meso-scale structure of cloud systems as well as the large-scale structure [2, 3, 4, 5]. The meso-scale structure is often better shown by the "narrow angle" camera. This camera when pointing vertically downward from a height of 380 n. mi., photographed an area whose diagonal was about 85 miles across. This detail enables one to study several interesting features of "cloud streets."

Such long thin lines of clouds, or cloud streets, occur fairly frequently in the atmosphere. For example, Riehl et al. [6], in a study of cumulus cloud bands in the tropical Pacific, found that the bands were oriented parallel to the low-level wind flow. Kuettner [7] presented several examples in which cumulus cloud streets were parallel to the wind; he also discussed the meteorological conditions under which such cloud bands will align with the wind. He considered mainly cloud streets formed when cold air flows over warm surfaces, although other types were also mentioned.

The TIROS I narrow angle camera also photographed some cumulus cloud streets, and the relationship of the flow patterns to the orientation and other aspects of the streets shown in the pictures will be discussed below.

¹ This research has been supported by the National Aeronautics and Space Administration.

2. THE SATELLITE PICTURES

Figure 1 is a composite assembled from several narrow-angle pictures taken at 10-second intervals between 2030 GMT and 2033 GMT on April 1, 1960. The satellite was traveling from northwest to southeast which is from left to right in the composite. The camera axis was oriented slightly back and to the left at this time.

The white areas in figure 1 are probably all cumuliform clouds. Grand Cayman Island is relatively cloud-free while the western end of Cuba and the Isle of Pines are more cloud covered. The presence of such land features increases the confidence in the location and orientation of the cloud features.

Figure 2 is a schematic representation of the clouds shown in figure 1. The dashed outline defines the areal coverage of figure 1. The track of the satellite is shown by the arrow.

The composite and the schematic diagram indicate a greater concentration of cumulus clouds over the heated land areas of the Isle of Pines and Cuba than over the adjacent ocean areas. This is perhaps better shown by examining figures 3 and 4 which depict the detail of cloud masses over Cuba and over the Isle of Pines, respectively. (The shoreline of the islands is indicated by the white outline.) These figures show much more extensive cumulus activity over the heated islands than over the adjacent ocean areas.

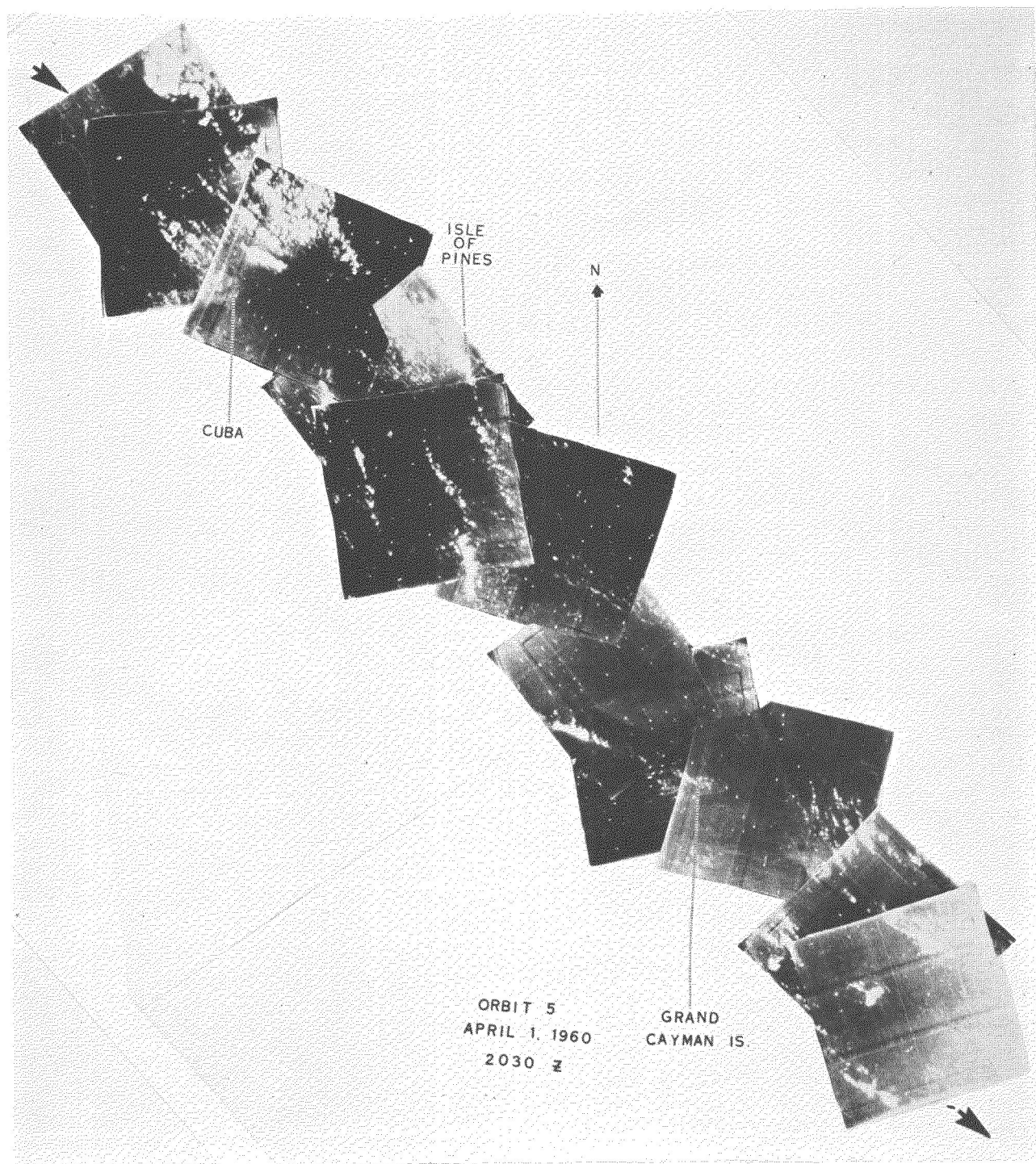


FIGURE 1.—Mosaic of narrow-angle pictures taken at 10-sec. intervals between 2030 and 2033 GMT, April 1, 1960.

This more extensive convective activity is apparently indicative of the greater instability over the islands. In figure 5, comparison of the 0000 GMT, April 2, 1960 radio-sonde observations at Havana (considered representative of the heated air over the island of Cuba) with the radio-sonde at Grand Cayman (considered representative of the oceanic air) shows the Grand Cayman sounding to be more stable and drier, particularly in the layer from 900 to 800 mb. Differences in heating doubtlessly account for much of this stability difference. An inspection of the sounding for 0000 GMT, April 2 and for 12 hours earlier (not shown here) at Havana (land influence) and at Grand Cayman (oceanic influence) shows that the lower layer at Havana experienced considerably more warming between early morning and evening than did the lower layer at Grand Cayman.

3. CLOUD STREETS IN RELATION TO THE WIND FIELD

The tendency for cumulus clouds to line up in bands or streets under certain conditions has been pointed out [6, 7]. Kuettner [7] discusses some conditions required for the convectively formed clouds to align in bands parallel to the wind. In his observation, the wind direction was fairly constant throughout the convective layer; but a wind-speed maximum also existed within the convective layer giving a negative mean curvature. The important parameter, according to Kuettner [7], in determining whether such bands will align with the wind is the mean curvature of the vertical profile of the horizontal wind speed within the convective layer. He found typical values of this speed-curvature to be of the order of $-10^{-7} \text{ cm.}^{-1} \text{ sec.}^{-1}$

Figure 6 shows the wind direction and speed at Havana and at Grand Cayman as a function of height. (Note: The 0000 GMT April 2 wind record for Havana was missing; therefore the 1200 GMT April 1 wind sounding was used. This difference is probably not serious since the synoptic situation in this region was generally unchanged in this 12-hour period.) The Grand Cayman wind profile (fig. 6b) shows a well defined, broad wind speed maximum in the lower layers while Havana (fig. 6a) shows a poorly defined slight maximum at 10,000 feet. Although the wind maximum may not be significant for Havana, computation of the mean curvature in the first 12,000 feet indicated that at both stations the wind profile curvatures were negative, and the curvature had values within an order of magnitude of $10^{-7} \text{ cm.}^{-1} \text{ sec.}^{-1}$

The cloud mosaic (fig. 1) and cloud schematic (fig. 2) show the cloud bands in the vicinity of the Isle of Pines and Cuba oriented at about 140° , and the three cloud bands just southeast of the Isle of Pines oriented at 150° – 160° . Referring to figure 6a, it can be seen that the winds at Havana in the first 12,000 feet were within 30° of these orientations. In the layer from 2,000 to 12,000 feet, the wind at Grand Cayman was between 120° and 140° . Thus the cloud streets are aligned quite

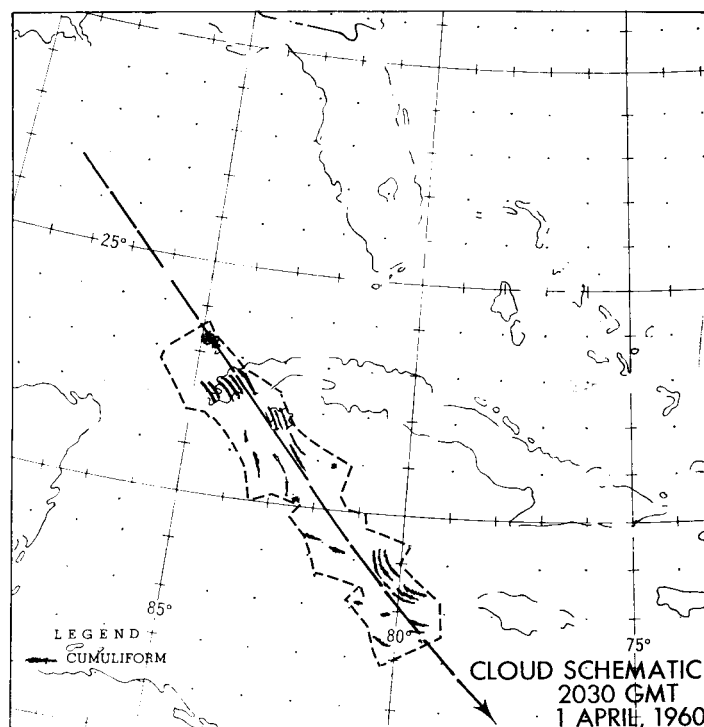


FIGURE 2.—Map showing schematic representations of cloud features appearing on the mosaic of figure 1. The irregular outline delineates geographic coverage of the mosaic. The track of the satellite is indicated by the arrow.

closely with the wind direction in the convective layer at the two stations.

Satellite pictures present an opportunity to observe spacing, shape, and other characteristics of cloud bands. For example, the three cloud bands immediately south and southeast of the Isle of Pines just mentioned (see fig. 1) are interesting because of their length and of the large distances between them. Figure 7 shows these three bands in greater detail. The distance from the easternmost band in figure 7 to the middle one is about 20 miles, and from the middle band to the westernmost one is about 30 miles. The length of the middle band (neglecting the brighter portion in the south which may be part of another cloud band) is about 30 miles, and of the other two about 50 miles.

Noting again figures 3 and 4, one can see that over the heated land masses of the Isle of Pines and Cuba the spacing of the bands is an order of magnitude smaller than the spacing over the ocean. Over Cuba the spacing is about 3 to 4 miles; over the Isle of Pines it is about 2 to 3 miles. Moreover, the length of these lines appears to be related to the distance across the island in the direction of the wind flow. For example, the bands (fig. 3) over extreme western Cuba are shorter than those farther east over Cuba; the bands over the very narrow southwestern portion of the Isle of Pines (fig. 4) are much

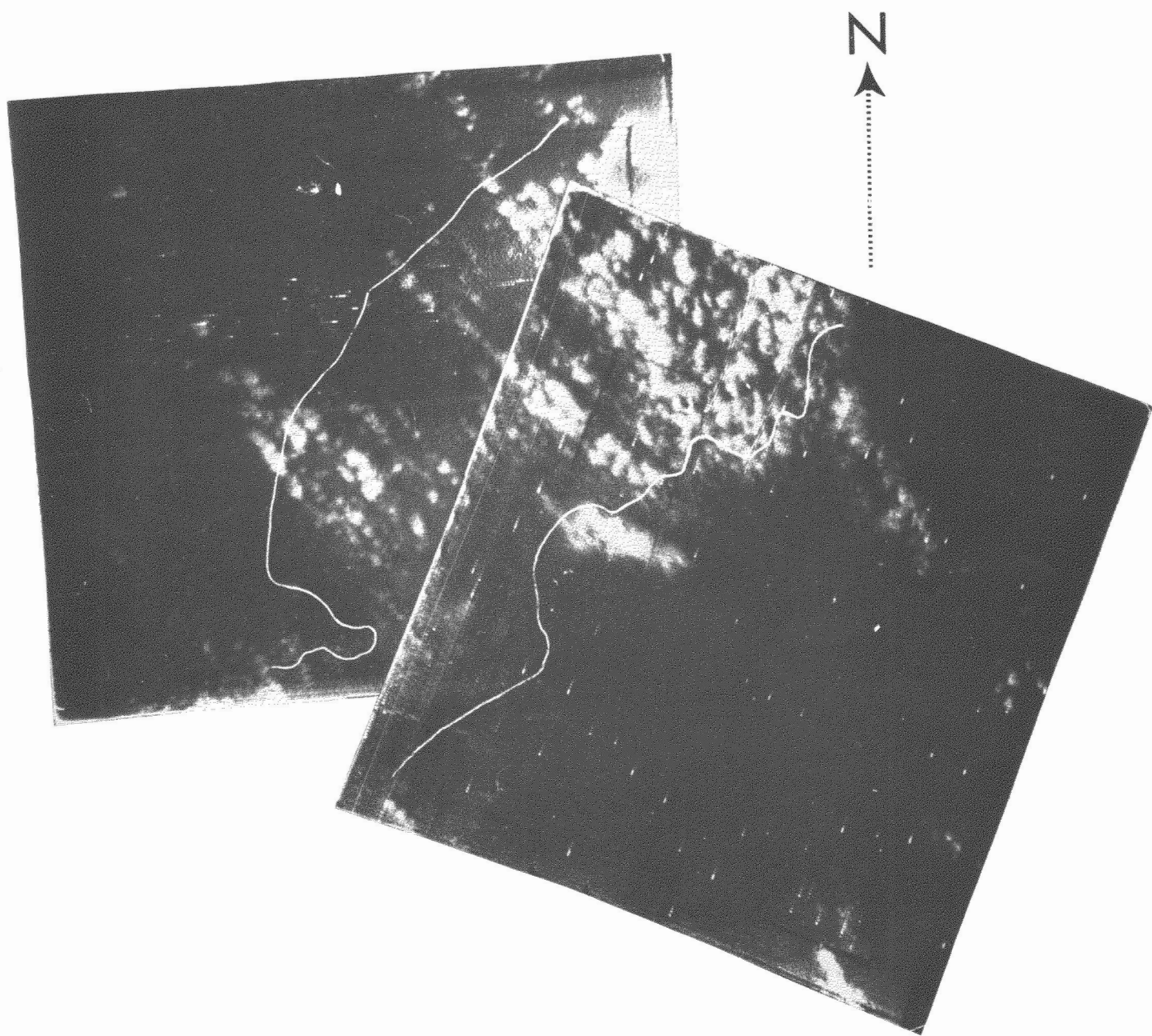


FIGURE 3.—Detailed composite of the portion of the mosaic over Cuba. The Cuban coastline is shown by the white outline.

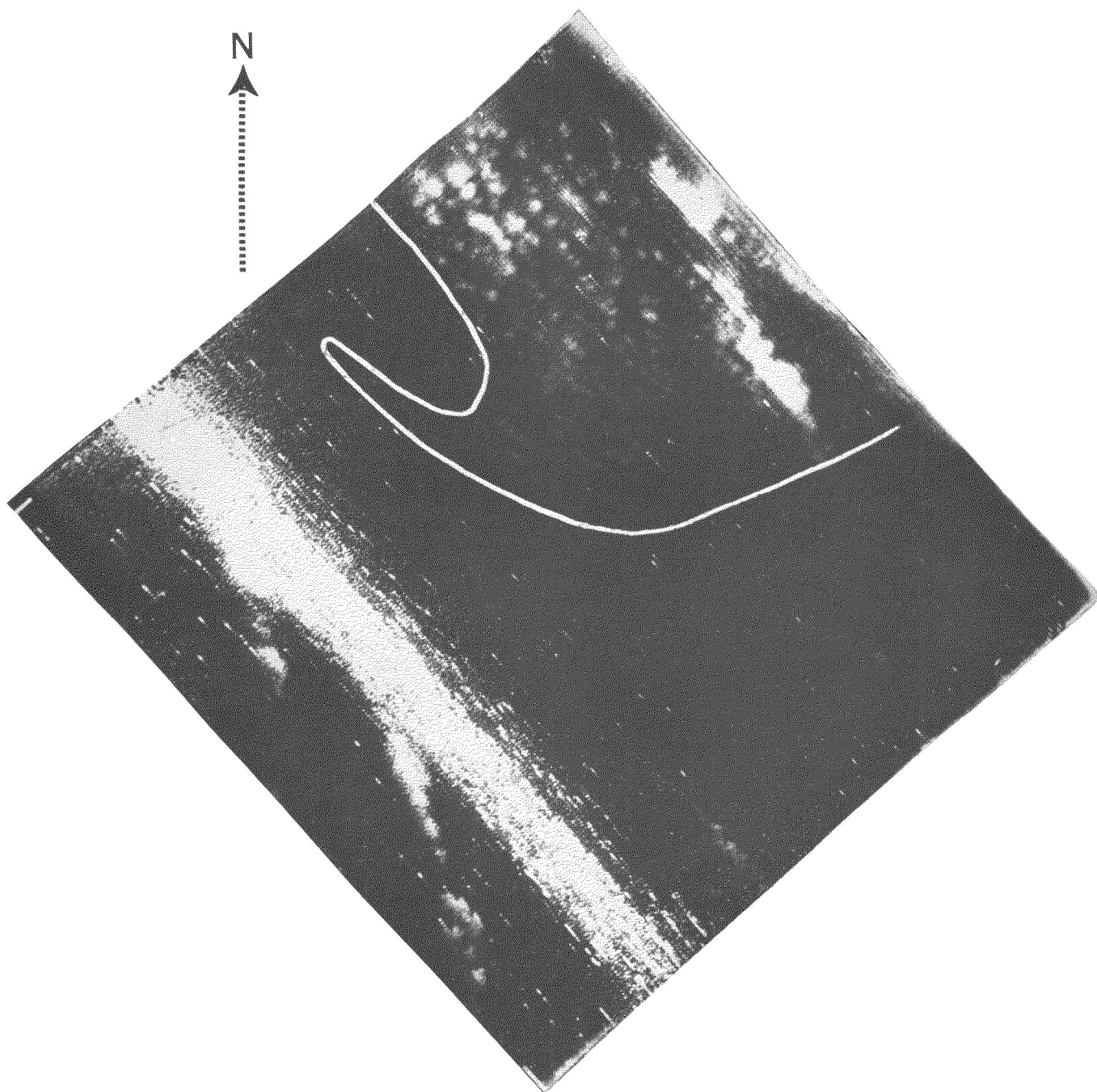


FIGURE 4.—Detailed view of cloud streets over the Isle of Pines. The coastline is depicted by the white outline.

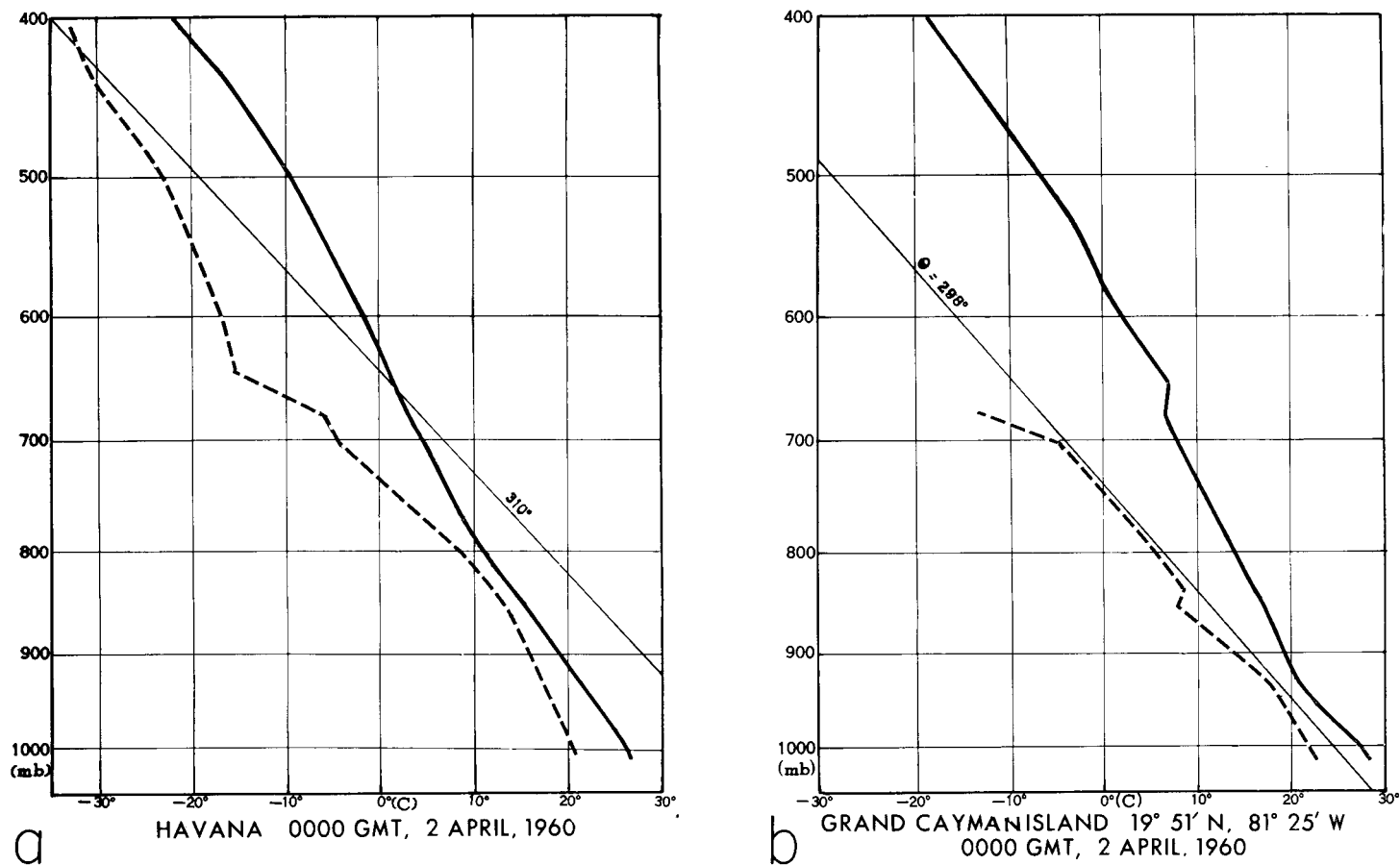


FIGURE 5.—Radiosonde observations for Havana and Grand Cayman Island at 0000 GMT, April 2, 1960.

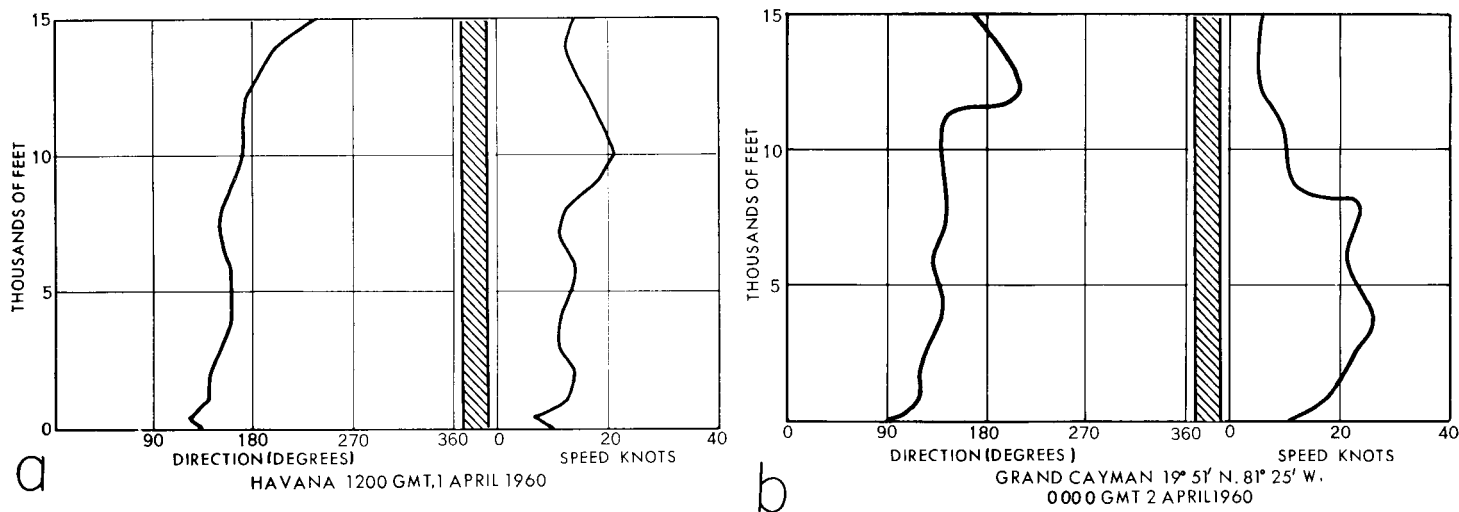


FIGURE 6.—Graph of wind speed and direction as a function of height for Havana at 1200 GMT, April 1, 1960 and Grand Cayman at 0000 GMT, April 2, 1960.

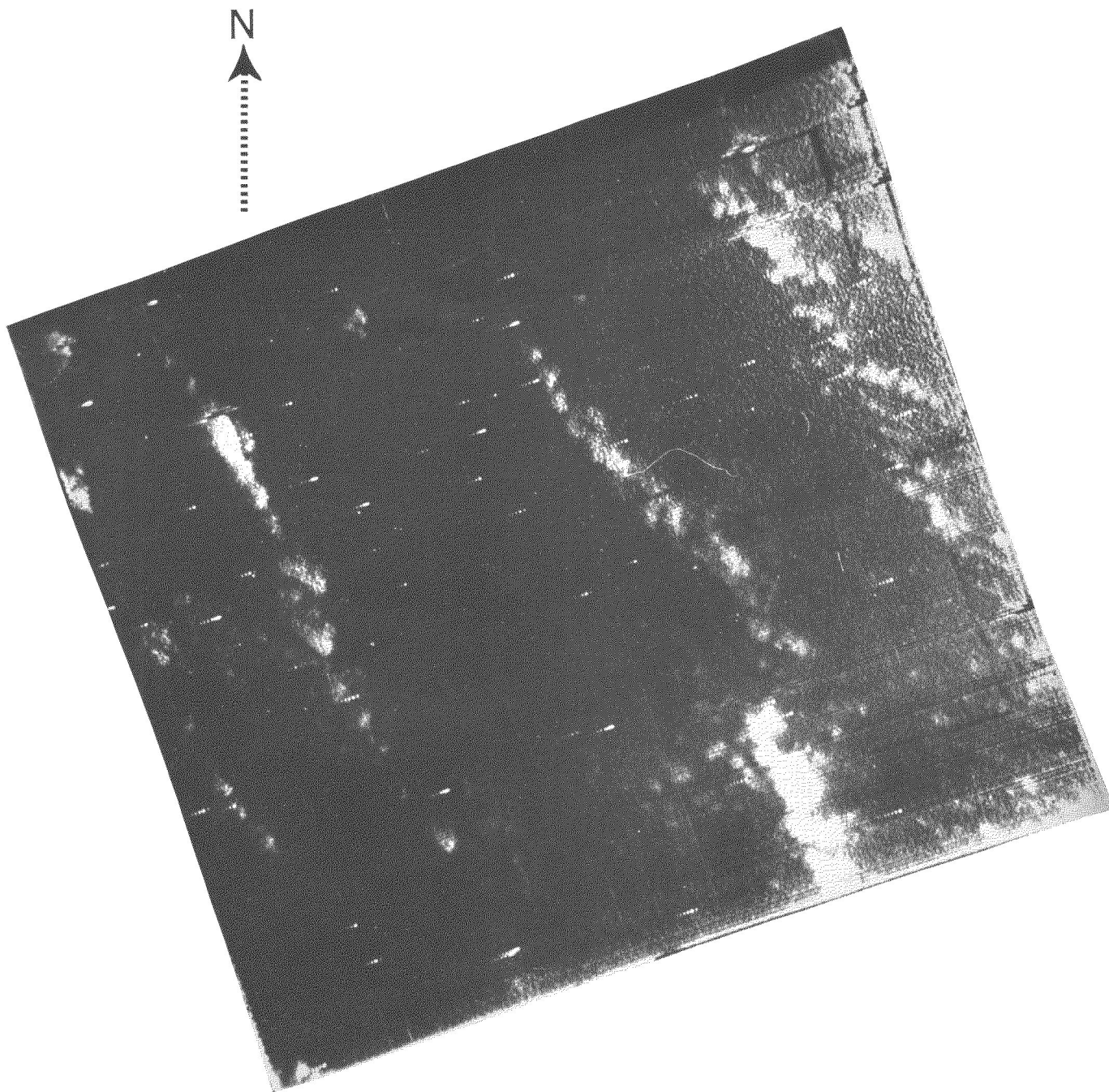


FIGURE 7.—Larger picture of the three oceanic cloud bands in figure 1.

shorter than those over the northeastern portion of the island. The distances across the islands in the direction of the wind flow vary in a similar manner.

In the extreme southeastern end of the picture swath, some anticyclonically (?) curved bands, which were imbedded in the general southeastern flow, were noted (see figs. 1 and 2). These are illustrated more clearly in figure 8. The radius of curvature of these bands is 60 n.mi. and they are spaced at 3 to 4-n.mi. intervals. Meteorological observations in this area were too sparse to determine whether a circulation of such a small scale existed. Nevertheless the curvature in the cloud street suggests

that such small undulations in the circulation may have existed.

4. SUMMARY

The TIROS narrow-angle camera presents a means of determining such factors as orientation, spacing, and length of cloud streets. In this study the streets were aligned within 30° of the wind direction in the convective layer. The spacing of the streets over heated land was much less than of those over the ocean. The length of the streets over the larger islands appeared to be related to the distance across the island in the direction of the wind flow.

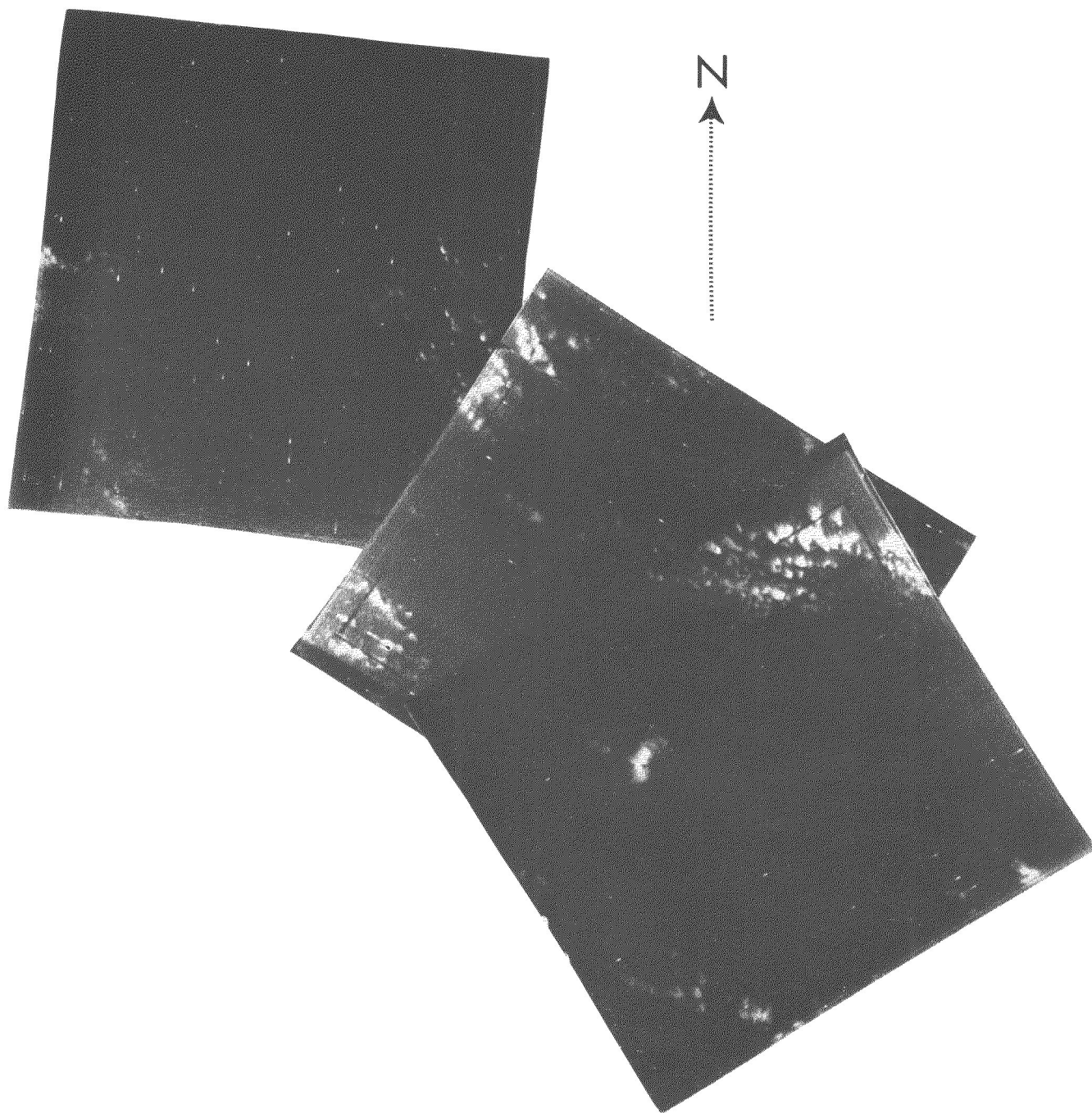


FIGURE 8.—Composite showing greater detail of the curved bands in figure 1.

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